Final Project Report to

The Office of Naval Research

by

The Department of Physics
Montana State University
Bozeman, Montana 59717

for

Beam Combining of Excimer Lasers by Stimulated Raman Scattering

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Principle Investigator: ______ Date: 6-12-90

John L. Carlsten

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Abstract of Completed Project

The primary objective of this research was to determine those factors which would influence the gain in a Raman amplifier that was pumped by a broadband excimer laser. Initial studies concentrated on determining the spatial structure from a Raman generator. The spatial structure was understood in terms of propagation in a quadratic index media. This well characterized generator output was then injected into a Raman amplifier for gain enhancement studies. This research indicated that a multimode, random phase model for the broadband pump could be used to predict the gain enhancements observed. However, our most recent data indicates that the model fails to account for the transiency found in lower pressure Raman amplifiers. However, further studies will be necessary to resolve this issue.

II. Abstracts of Theses

GAIN ENHANCEMENT IN A XeCl PUMPED

RAMAN AMPLIFIER

by

Jeffrey Rifkin

A Thesis submitted in partial fulfillment

of the requirements for the degree

of

Master of Science

in

Physics

MONTANA STATE UNIVERSITY

Bozeman, Montana

December 1987

ABSTRACT

Gain enhancement in an excimer-pumped Raman amplifier consisting of molecular hydrogen is experimentally measured. Gain enhancement is measured both as a function of optical delay and input pump intensity, and in the two limits when the laser modespacing is large, and comparable to the linewidth associated with the Raman medium.

Experimental results are compared with the predictions of a transient multimode theory. This theory is based on the coupled equations of Raman scattering which describe the transient growth of the Stokes field and coherence of the Stokes transition. A sum over longitudinal modes with fixed and totally random phases is assumed for both the pump laser and Stokes fields.

The theory compares well with experiment in the regime where the Raman linewidth is large compared to the modespacing of the laser. The theory also makes the interesting prediction that in this limit, the broadband gain will be larger than the gain for a narrowband laser.

STIMULATED RAMAN SCATTERING IN 10 AND 100 ATMOSPHERE MOLECULAR HYDROGEN

by

Michael Jack Runkel

A thesis submitted in partial fulfillment
of the requirement for the degree

of

Masters of Science

in

Physics

MONTANA STATE UNIVERSITY

Bozeman, Montana

December 1989

ABSTRACT

This thesis presents a study of Stimulated Raman Scattering in 10 and 100 atmosphere molecular hydrogen using a broadband, multimode, xenon chloride excimer laser operating at ultraviolet wavelengths. Stimulated Raman Scattering was initiated in the medium using optimally aligned pump (308 nm) and Stokes (351 nm) beams. Raman gain data was collected for the cases of well-correlated and uncorrelated pump and Stokes beams. Theory was fit to data via numerical calculation using the muldimode, fixed random phase and temporal square pulse models with variable pulse length as fitting parameter. Results of the data fits were compared to the results of previous work, used to compare the 10 and 100 atmosphere cases, and to account for differences between the correlated and uncorrelated results at fixed pressure. Comparison of the pulse times derived from numerical data fitting and from measurements of peak power density showed agreement to within the error bars found in the experiment.

Additional topics intended to supplement the main body of the thesis include a formal development of Riemann's method for the solution of second order hyperbolic partial differential equations, and its application to the Raman equations, and a characterization of molecular hydrogen as a Raman scattering medium using elementary quantum mechanics and spectroscopic theory.

III. Publications and Presentations

1) "Spatial Mode Structure in Stimulated Raman Scattering," contributed paper at the First International Laser Science Conference, Dallas, Texas, November 1985 (with J. Rifkin).

2) "Spatial Mode Structure of Stimulated Stokes Emission from a Raman Generator," J. L. Carlsten, J. Rifkin and D. C. MacPherson, JOSA B3, 1476 (1986).

3) "Spatial Mode Structure of Stimulated Stokes Emission from a Raman Generator," J. L. Carlsten, J. Rifkin and D. C. MacPherson, Advances in Laser Science-I, AIP Conference Proceedings No. 146. Ed. William C. Stwalley and Marshall Lapp, (1986) 316.

4) "Gain Enhancement in a XeCl Pumped Raman Amplifier," contributed paper at the XV International Conference on Quantum Electronics, Baltimore, Maryland, April 1987 (with J. Rifkin, M. L. Bernt and D. C. MacPherson).

5) "Role of Transiency in the Gain Enhancement of a Raman Amplifier," invited paper at the SPIE symposium on Lasers and Optics, Los Angeles, California, January 1988.

6) "Gain Enhancement in an XeCl Pumped Raman Amplifier," J. Rifkin, M. L. Bernt, D. C. MacPherson and J. L. Carlsten, JOSA B5, 1607 (1988).

7) "Role of Transiency in the Gain Enhancement of a Raman Amplifier," J. Rifkin, M. L. Bernt, D. C. MacPherson and J. L. Carlsten, SPIE, Vol. 874, 39-45 (1988).

IV. Technical Summary

This research was initiated to determine the factors which would influence the gain in a Raman amplifier which was pumped by a broadband excimer pump laser. Specifically we hoped to be able to make a detailed comparison of the growth of the Stokes wave in the Raman amplifier with multimode theory. This comparison would then give credibility to models based on the multimode theory.

Before measuring the gain in a Raman amplifier, we needed to accurately determine the spatial mode structure of the content of a Raman generator which would be used for the injection source. In these studies the spatial mode structure of the stimulated Stokes emission from a H_2 Raman generator was accurately determined using a linear photodiode array and imaging techniques. The spatial problems were compared to the predictions of Yariv's theory of propagation in a quadratic gain medium applied to Raman scattering. Agreement with the theory was found at low intensities where the profile was found to be very gaussian. However, the spatial profile at higher intensities could not be treated by the theory. Nonetheless, we had well documented injection sources for the amplifier experiments.

Following our studies of the spatial mode structure of the stimulated Stokes emission from a Raman generator, we proceeded to inject this well characterized Stokes beam into a Raman amplifier to experimentally determine the gain enhancement possible. We were, in particular, interested in obtaining experimental measurements that could be compared in detail with the multimode model for Raman scattering. The excimer laser was used to pump both a Raman generator and a Raman amplifier. A variable delay in the Stokes beam allowed the optical path difference to be zeroed and the maximum gain to be obtained. The gain enhancement results

from the mutual coherence between the Stokes beam (exiting from the Raman generator) and the pump beam.

We found that the gain enhancement was approximately in the ratio of the laser bandwidth to the Raman bandwidth. A detailed comparison with the random phase, multi-mode theory resulted in excellent agreement. The details of the comparison are given in the references listed.

At this point we felt it was necessary to test the theory further by taking data at several pressures and seeing if a zero parameter fit would agree with the data. However, we found that while the data at 100 atmosphere pressure fit the theory quite well, at 10 atmosphere pressure the comparison was far from agreement. In fact, we found that we could not fit the data with any reasonable choices of the parameters. It appears that transiency was starting to play a role and to verify this, the model would have to be modified to include the effects of transiency and specific laser pulse shape. Unfortunately at that time, the program was nearing its completion and we were not able to see if theses conjectures were correct. As a result of this discrepancy, this latest data has not been published but is part of the second thesis listed in section II B.